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MORTALITY CAUSED BY ROOT DISEASES AND ASSOCIATED PESTS ON SIX NATIONAL FORESTS IN ARIZONA AND NEW MEXICO

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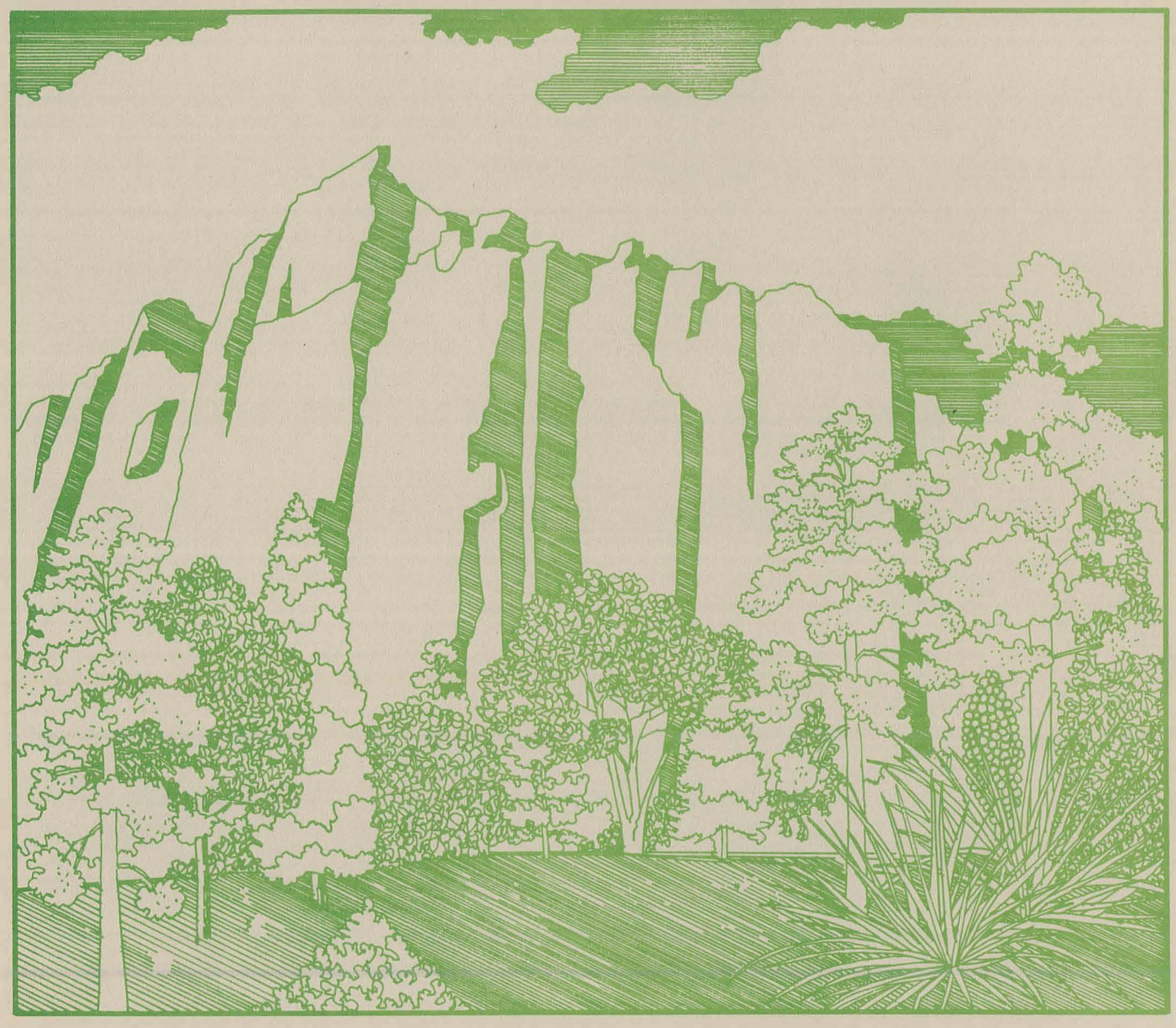

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MORTALITY CAUSED BY ROOT DISEASES AND ASSOCIATED PESTS ON SIX NATIONAL FORESTS IN ARIZONA AND NEW MEXICO

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By

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ABSTRACT

A survey of commercial timber-producing lands on six National Forests in Arizona and New Mexico determined numbers of trees, and volumes therein, killed by root diseases and associated pests. Mortality overall was light and scattered, about 0.08 trees per acre per year, representing 12 board feet per acre.

Root diseases and associated pests were responsible for about 34 percent (79,235) of the trees killed, and about 30 percent (9.7 million board feet) of the volume lost. A larger proportion of the mortality was attributed to these pests in mixed conifer and spruce-fir stands than in ponderosa pine stands. Shoestring root rot was associated with the death of about 78 percent of the root-diseased trees, containing about 80 percent of the volume lost; annosus root rot was found in the remainder. Effects of the two root rots, the implications to land managers, and alternatives for managing infected stands are discussed.

INTRODUCTION

Root diseases are important causes of tree mortality nationwide, but their importance varies according to geographical area. No National Forest- or Region-wide estimates for losses caused by root diseases have been made in the Southwestern Region, although limited surveys and biological evaluations indicate that root diseases have been a local concern to managers. These estimates are needed in order to determine the effects of root diseases and associated pests on management objectives.

Accordingly, we determined numbers of trees and volumes killed in 1 year by root diseases and associated pests in selected commercial timber types on the six National Forests in northern New Mexico and Arizona, which together produce approximately 85 percent of the commercial wood fiber harvested from National Forest System (NFS) lands in the Southwestern Region (1). We also field tested a survey method, the pest damage inventory (PDI), developed and used in the Pacific Southwest Region, in order to determine its applicability elsewhere. The PDI is designed to measure mortality of all conifer species from all causes within areas selected.

METHODS

The following is a generalized account of the methods used, containing modifications made to suit conditions unique to the Southwestern Region. Brief descriptions of the methods used in the Pacific Southwest Region are contained in various reports and evaluations (11,12, 15). A complete, detailed account of the PDI methods is in press (4).

Sampling Scheme

All townships containing more than 50 percent NFS lands in the Apache-Sitgreaves, Coconino, and Kaibab National Forests in Arizona, and the Carson and Santa Fe National Forests in New Mexico, were assigned numbers. The numbered townships were divided into 81 potential photoplots, each 284 acres in size. The acres and timber type(s) of NFS land on potential plots, drawn at random, were determined using standard type maps. If the acreage of a potential plot was more than 50 percent commercial forest land of a single timber type, it was selected as a first stage sampling unit. Plots were selected until the acreage in the first stage sample slightly exceeded 1.5 percent of the total acreage for each stratum. The geographical areas, timber types, numbers of primary sample units or photoplots, and sampling intensity are as follows:

Primary sample unit and timber type (stratum)	No. primary sample units	Actual intensity (%)
Northern New Mexico* pine	35	1.4
Northern New Mexico mixed conifer	17	1.3
Northern New Mexico spruce-fir	6	1.8
Apache-Sitgreaves pine	28	1.7
Apache-Sitgreaves mixed conifer	10	2.2
Coconino pine	36	1.6
Kaibab pine	29	1.6

The boundaries of the selected photoplots were then transferred to USGS 7.5- and 15-minute quadrangle maps and to 1:15,840 or 1:24,000 scale aerial photographs. North-south flight lines were also drawn on the maps and photographs, and appropriate flight elevations assigned.

Aerial photographs were taken at a scale of 1:8,000 using a Zeiss RMK camera, an 8.25-inch lens, HF 3 or 4 haze filters, an antivignetting filter, and Ektachrome MS (Kodak 2448) film. Enough photographs, usually five, were taken of each photoplot to insure stereophotograph coverage. The photographs were taken between May 24 and June 12, 1981, using an aircraft and crew provided by the Pacific Southwest Region, and a camera supplied by Rocky Mountain Forest and Range Experiment Station.

A number of selected plots could not be photographed because of bad weather. Accordingly, an improvised method of substitution was used

* Northern New Mexico strata consist of the Carson and Santa Fe National Forests, which were combined because of similarity in terrain and climate.

in an attempt to acquire the needed number. The aircrew was told to photograph each plot if possible; if it was obscured by clouds below flight elevation, or partly shadowed, a nearby area estimated to have the same timber type was photographed instead and, when possible, the approximate location of the improvised plot was transferred to the resource photography used in making the flight. Film was developed by a commercial firm specializing in aerial film processing.

Photointerpretation was done in the following manner. Photoplot boundaries were transferred from the quadrangle maps to the transparency which best centered it (the plot photograph) using an Old Delft stereoscope. Photographs were interpreted for all conifers at least 25 feet tall and 5 inches d.b.h. which, in the interpreter's estimation, died up to 1 year before the photographs were taken. Trees were considered current mortality if the foliage was chartreuse, yellow, or sorrel. Trees without visible needles were not considered current mortality, nor were trees containing any normal green foliage. Individual dead trees or groups of trees, called mortality groups, were circled on each plot photograph and sequentially numbered. The number of trees in each mortality group was recorded and selection numbers assigned according to the number of trees in the group. Photointerpretation was done using portable light tables and 4X stereoscopes. Plot delineation and photointerpretation of northern New Mexico and the Apache-Sitgreaves National Forests were done inhouse; on the Kaibab and Coconino National Forests, the work was performed by a contractor.

A subsample, consisting of one-third of the photoplots, was chosen using probability proportional to size (number of dead trees). Six mortality groups were then chosen from each subsampled photoplot, again using probability proportional to size, for ground checking.

Field crews located selected mortality groups on the ground. All current conifer mortality larger than 5 inches d.b.h. located within the areas circled on plot photographs, including that not visible on photographs and not counted by the photointerpreter, was counted and measured (d.b.h., height). Basal area was determined using a prism. Age and height of a fast-growing, healthy tree located near each mortality group were determined in order to estimate site quality. All trees were examined closely and systematically for insects and diseases which contributed to decline and death. Upper crowns and boles were observed from the ground for characteristic signs of pests occurring there. Bark was removed from portions of the bole within reach of the ground, and roots were excavated as appropriate, in order to identify pests inhabiting the lower bole and roots.

RESULTS

A total of 233,043 ± 5,886 trees larger than 5 inches d.b.h., containing 33,559,985 ± 2,668,522 board feet (BF), Scribner rule, died between June 1980 to June 1981 on the 2.8 million acres surveyed

(table 1). An average of 0.08 trees, containing 12 BF, died per acre. Losses varied widely among strata, ranging from a low of 0.04 trees per acre (Apache-Sitgreaves pine stratum) and 6.0 BF per acre (New Mexico pine stratum) to a high of 0.15 trees per acre and 36.4 BF per acre (Apache-Sitgreaves mixed conifer stratum).

Root diseases almost always acted as one or more agents in a complex which also included dwarf mistletoes or bark beetles; only rarely were root diseases found alone or with both dwarf mistletoes and bark beetles. Overall, about 34 percent of the mortality and 30 percent of the volume lost were attributed to root disease complexes (table 2 and figure 1). Frequency of occurrence of complexes containing root disease varied widely among strata, from about 4 percent of both trees killed and volume lost in the Kaibab pine stratum to 93 percent of the trees killed, and 99 percent of the volume lost, in the New Mexico spruce-fir stratum (figures 2 to 8).

The PDI, while it recognizes and emphasizes that mortality is often caused by a complex of agents, also can present estimates of mortality as if caused by a single pest (table 3). The estimates are obtained by dividing numbers of dead trees and volume losses attributed to a pest complex by the number of pest species in the complex, then summing trees and volumes for each pest. Western pine beetle (Dendroctonus brevicomis) caused the death of 38,061 trees, or 17 percent of the total, and 9,741 MBF, or 35 percent of the volume estimated by this method. Shoestring root rot, caused by Armillariella mellea, and annosus root rot, caused by Fomes annosus, killed approximately 34,816 trees, or 16 percent of the total, containing 4,834 MBF.

Shoestring and annosus root rots together accounted for essentially all of the mortality attributed to root diseases (table 4). Shoestring root rot was encountered much more frequently than annosus root rot in all strata, and resulted in much greater volume losses. Mortality attributed to this pathogen ranged from about 2 percent of both trees killed and volume lost in the Kaibab pine stratum to 38 percent of the trees killed, and 44 percent of the volume lost, in the New Mexico spruce-fir stratum. Losses caused by annosus root rot, on the otherhand, did not exceed 14 percent of the trees killed and 11 percent of the volume lost in any strata, and in five of the seven strata, it contributed to less than 1 percent of both dead trees and volume lost. Greatest losses attributed to either disease occurred in the mixed conifer and spruce-fir timber types.

The relationship of mortality and volume loss to site quality is shown in table 5. Over half of the mortality and volume loss occurred on low quality sites roughly corresponding to site III (30-65). Approximately 71 percent of the total productive area, land capable of producing more than 20 cubic feet of wood per year of the forests surveyed, falls into this site class (1).

About 64 percent of the trees that died, containing over 75 percent of the volume lost, were ponderosa pines (table 6). Eighty-seven percent

of the commercial forest acreage of all ownerships in Arizona and 64 percent of the acreage in New Mexico are in the ponderosa pine type (1).

DISCUSSION

An estimated 233,043 trees, containing 33.6 million BF, died in the survey area. This represents about 11 percent of the average annual timber volume, including sawtimber and pulpwood, sold in the Southwestern Region between 1972 and 1981. For a number of reasons (see Critique section), we consider the estimate of dead trees to be much lower than the actual number which died. Volume loss estimates are probably more accurate, but are certainly lower than the total volume lost. Losses not measured include trees smaller than 5 inches d.b.h., growth losses which occur either prior to tree death or which result from sublethal agents acting over time, and area out of production as a result of persistent agents. Other studies (3) have shown that these losses are serious, and may equal or exceed mortality losses; however, they cannot be measured by the methods used.

Trees killed by pests in forests managed for timber production represent a loss in terms of timber values, even when they are salvaged or used for fuelwood because the monetary return is less. The reduction in timber values is, to a certain extent, offset by positive effects on other resources which are important even in stands or forests managed for timber. Snag-dependent wildlife species, for instance, require a more or less continuous supply of large snags created from mature or overmature trees; these species decline in numbers when conifer stands are managed on short rotations at stocking levels designed to maximize wood fiber production (13). Even if the overall estimate of mortality found in the study area, 0.08 trees per acre, is doubled to account for the error of omission, it is probably little more than that necessary for habitat maintainence.[1]

In the six National Forests surveyed, levels of mortality varied widely both between (table 1) and within strata. For instance, while the average number of dead trees per photoplot in the Apache-Sitgreaves mixed conifer stratum was 58, the number of dead trees on the 10 photoplots ranged from 26 to 158. The range in the most uniform stratum, Coconino pine, where the average mortality was 18 trees per plot, was 3 to 47 trees. Even distribution of tree mortality has the desirable effect of dispersing snag-dependent wildlife, resulting in maximum use of snags by these species.[1] Negative effects of tree mortality on other resources are minimized when it is evenly distributed. The fact that mortality is not evenly distributed means that real timber losses are greater than the averages indicated; at the

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[1] Personal communication with Roger Bumstead, USDA Forest Service, Southwestern Region, Wildlife Management, Albuquerque, New Mexico.

same time, the benefits to snag-dependent wildlife and other resource values are reduced. Conversely, concentrated mortality provides a greater opportunity to deal with pests or to salvage dead material.

Surveys in southern New Mexico (7), southern Colorado (6), and other parts of the West (5, 12, 15) have established the importance of pest complexes as causes of tree mortality. These complexes, typically combinations of insects or insects and diseases, acting together or in succession, were also major causes of tree mortality in the forests of northern New Mexico and Arizona. Bark beetles (*Dendroctonus*, *Ips*, *Scolytus*, and others) occasionally were the only pests identified in ground-checked trees, but generally they and the other important classes of pests, root diseases and dwarf mistletoes, were found in various combinations.

Observations, and the results of biological evaluations, have suggested that shoestring root rot is the most important root disease in the Southwestern Region. We found this to be true for the study area as a whole; the disease killed about three times as many trees and contributed to over four times as much volume loss as annosus root rot. *Armillariella mellea*, the cause of shoestring root rot, was found to be an aggressive pathogen in all strata except in the Kaibab pine, where almost no root diseases were observed. Observations indicate that both shoestring and annosus root rots are common, however, in mixed conifer and spruce-fir stands on the Kaibab National Forest, north of the Grand Canyon.

Biology and Management of Shoestring Root Rot

Shoestring root rot is both a common forest pathogen and saprophyte in temperate and tropical regions in the Northern Hemsiphere, and affects a wide range of hardwoods and conifers, including all the commercial tree species in the Southwestern Region. It typically invades roots and root collars of stumps or dead trees by means of airborne spores, and utilizes the invaded substrate to develope inoculum potential. Nearby live trees are then infected through root contacts or by means of rhizomorphs, slender stringlike strands of fungal material resistant to unfavorable environmental factors and antagonistic agents, which have the ability to grow through soil and litter. Cambium of infected trees is killed, and the sapwood decayed upward to, and as much as 3 feet above, the root collar. Trees rapidly killed by the fungus include all seedlings and saplings; older, unthrifty trees; and trees of any size or vigor in close proximity to an inoculum source. Infected but otherwise vigorous pole- and sawtimber-sized trees survive for indefinite periods of time, although with reduced growth rates, unless overwhelmed by high inoculum levels or by bark beetles which often attack infected and weakened trees.

Three examples from around the Southwestern Region illustrate the types of losses incurred. On the Apache-Sitgreaves National Forests, high mortality levels caused directly by shoestring root rot in seedlings, associated with and predisposed by poor planting techniques

which cause J-rooting, were reported in ponderosa pine plantations.[2] On the Santa Fe National Forest, 10 percent of the sawtimber-sized ponderosa pines, containing about 1,000 BF per acre, and about 12 percent of the poles and saplings, were killed in an area of about 600 acres within 8 years after a partial overstory removal cut was made (16). On the Carson National Forest, in a stand composed of Douglas-fir and white fir, 25 percent of the area is out of production due to the presence of shoestring root rot, and the fungus appears to be spreading to residual trees.

Because it invades fresh-cut stumps and wounds created during stand entries, and survives in them for relatively long periods, management of shoestring root rot through silvicultural practices is difficult. Partial control can be achieved by practices aimed at promoting tree vigor, preventing infections, and minimizing the amount of material available for occupation by the fungus.

Survival of natural or planted seedlings in infected regeneration areas is increased by many of the practices used to insure survival in normal regeneration areas, such as selecting tree species most suited to the site, careful site preparation, and using proper planting practices. However, the common practice in the Southwest of planting seedlings in the shade of stumps, in order to provide partial protection from intense sunlight, exposes them to very high inoculum levels when the shading stumps are infected by root diseases.

As mentioned earlier, all commerical Southwestern tree species are susceptible to shoestring root rot. Nonresinous conifers, such as true firs and spruces, are more susceptible than Douglas-fir and ponderosa pine. Aspen, on the other hand, is seldom infected.

Conversion of a heavily infected site to aspen for a short rotation allows time for the fungus to die out in conifer stumps and roots. Species conversion may not be feasible in some cases because it fails to satisfy management objectives or because aspen is not adapted to the site.

In the Pacific Northwest, stumps are pushed using a bulldozer equipped with a ripper, or extracted with a specially designed stump puller (9). This procedure removes all of the bulk of the stump and most of the roots which constitute the source of infection. It disrupts the tissues of the remaining roots, exposing the pathogen to the action of competing and antagonistic organisms. Stump removal, as might be imagined, is expensive and creates heavy fuels, but it can be combined with site preparation for better economy. Russell (10) estimated that the cost of removing ponderosa pine stumps in southwestern Washington

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[2] Personal communication with Tom Clifford, USDA Forest Service, Apache-Sitgreaves National Forests, Springerville, Arizona.

in 1981 was about $2.43 per stump (average diameter 18 inches) when done with a D-8-sized tracked vehicle. The cost increased to about $2.60 per stump when a stump puller was used.

We have observed that heavy disks, when used in the Southwest to prepare sites for regeneration, often disrupt stumps and shallow roots. It is possible that inoculum potential could be significantly reduced if the stumps were deliberately disrupted with this equipment. The costs of the treatment would probably not be significantly greater than the cost of site preparation. Although stump removal or discing have not been tested in the Southwest as a means of controlling shoestring root rot, stumps have been removed on a limited basis as a means of accomplishing site preparation where large stumps are a hazard to equipment.[3]

Mortality caused by shoestring root rot in newly regenerated stands is typically high in the first decade, but gradually decreases thereafter as inoculum potential becomes less and tree vigor increases. For instance, about 25 percent of the seedlings in a pine plantation, Las Conchas, on the Santa Fe National Forest were killed by shoestring root rot by the time the plantation was 8 years old (14). When the plantation was examined 6 years later, no new mortality had occurred, although some older (2 to 5 years) mortality was observed.[4] Current mortality and symptomatic trees in the nearby Roger plantation, also established in 1962, showed a similar pattern. About 25 trees per acre per year died in 1976, and the rate of mortality was thought to be decreasing. In fact, it dropped to about 14 trees per acre per year by 1980, and was considered stable, limited to trees weakened by other factors.[5]

Early thinning to low stocking levels, in order to optimize growth of individual trees and reduce the size and amount of material available for occupation by the fungus, minimizes losses in young, root rot-infected stands. Stocking levels in Las Conchas and Roger plantations, even after 14 and 20 years of growth and mortality, were 700 and 600 stems per acre, respectively, an average spacing of 8 by 8 feet. These and similar plantations should be scheduled for thinning as soon as possible to a maximum of 275 stems per acre, or a spacing of about 12 by 12 feet.

<u>Biology and Management of Annosus Root Rot</u>

<u>Fomes annosus (Heterobasidion annosum)</u>, the cause of annosus root rot, is distributed worldwide, and infects a large number of conifer species

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[3] Personal communication with James Cooley, USDA Forest Service, Apache-Sitgreaves National Forests, Springerville, Arizona.
[4] Report R-3 76-35, 5230 letter from D. P. Graham to the Forest Supervisor, Santa Fe National Forest, Sept. 1, 1980.
[5] 3400 letter from D. L. Parker to the Record, Oct. 20, 1980.

and a few hardwoods. It causes serious losses in mixed conifer and spruce-fir forests throughout the West and in pine forests on the eastern slopes of the Sierra Nevada in California. In 1947, Mielke and Davidson (8) described _F. annosus_ as being "widely distributed but not common in the Southwest where it has been found killing certain conifers . . ." The present incidence of annosus root rot is probably close to that summarized by Mielke and Davidson, in that, while it is present in all strata, overall losses are low and occur mainly in true fir. Reasons for the low incidence of this root rot in the Southwestern Region are unclear. Conditions appear favorable for spread, in that a range of known host species are available, airborne spores are present, and susceptible substrates, in the form of fresh-cut stumps and wounded trees, are constantly created. Losses to this fungus have increased in Europe and the Southeastern United States as a result of intensive management of stands (2). It is possible that losses also will increase in the Southwest following repeated stand entries.

The disease cycle of annosus root rot is somewhat like that of shoestring root rot, although the differences between the two organisms result in slightly different management strategies. _Fomes annosus_, like _A. mellea_, is spread by means of airborne spores which land on freshly exposed wood, germinate, and colonize root collars and roots. Nearby live trees are infected by means of root contacts and grafts. _Fomes annosus_ does not produce rhizomorphs. Typical centers contain fading or symptomatic trees, as well as ones which have died over a period of years. Mortality is often associated with a stump or stumps, although the original point of infection might also be a wound on a living tree at or near the root collar. Although the fungus survives poorly in soil, it can live in infected wood for long periods of time. _Fomes annosus_ is unusual among root rots, in that it in effect causes two diseases, depending on the tree species attacked. In resinous species, such as pines, it is typically a cambium killer, and is restricted to the bark and outer sapwood. As a result, pines are usually killed soon after becoming infected. In nonresinous species, such as true firs, the fungus kills small roots, but, in the initial stages of infection, decays the inner sapwood and heartwood of larger roots and butt portions. Later, for reasons which are poorly understood, the fungus may move out and occupy the outer sapwood and inner bark, killing the cambium. Usually the losses caused by annosus root rot in firs are due to decay in butt logs, increased probability of windthrow, and increased susceptibility to insect attack (2). Observations in California indicate that annosus root rot often kills seedlings and saplings of ponderosa pine, but not of white fir, and suggest that the reason is greater resistance to the fungus (17) of sapwood, cambium, and phloem of white fir.

Techniques used to manage annosus and shoestring root rots are similar up to a point. Practices common to management of both pests include careful attention to regeneration and early, heavy thinning of stands. Neither stump removal nor discing has been tested as a means of eradicating _F. annosus_. Observations indicate that the fungus seldom is

transmitted via root contacts between different tree species (17), possibly because strains of the fungus are somewhat specialized. As a result, pine regeneration in centers initiated in white fir stands, or Douglas-fir regeneration in infected pine or spruce-fir stands, usually has a lower mortality rate than if the stand were regenerated to the same species, and the mortality that occurs is generally limited to seedlings and saplings in close contact to infected roots.[6] Conversion to another conifer species or aspen is probably the most effective means of managing the disease in mixed conifer and spruce-fir stands. It allows time for the fungus, which is capable of surviving in centers for as long as 50 years, to die out, while still maintaining at least partial productivity of the site. If species conversion is not practical, distinct, identifiable infection centers should be delineated and avoided when susceptible species are planted.

CRITIQUE

Advantages and disadvantages of the PDI are discussed elsewhere (4). The advantages are stated to be (1) efficiency and low cost, (2) ability to account for complex causes of tree mortality, (3) provision for estimates of reliability, and (4) wide applicability of results. Disadvantages are (1) the necessity for accurate photointerpretation accomplished in a very short period of time, (2) the need to conduct a ground survey separate from the ground check (although the same photoplots are used) in order to determine errors of omission, and (3) the concept of pest complexes does not fit the traditional format for reporting losses caused by insects and diseases.

Many of the advantages (and disadvantages) of the PDI are shared by other survey methods which utilize aerial photography and ground checking. The PDI is somewhat unusual in that it makes no assumptions as to the cause of mortality prior to ground checking; rather, it uses ground checking not only as a means of correcting the estimates of numbers of dead trees and volumes obtained from the photographs, but also uses it to determine, as nearly as possible, the full range of pests and site conditions which contribute to mortality. While this interdisciplinary approach appears to provide a more realistic estimate of pest-caused mortality, it requires adjustments to traditional attitudes.

The above list of advantages and disadvantages is, for the most part, valid for the PDI as conducted in the Southwestern Region, although it does not address several technical problems, or situations, which we encountered and which either increased the cost of the survey or decreased the reliability of the estimates. A brief discussion of these might benefit anyone considering a similar survey.

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[6] Personal communication with Richard S. Smith, Jr., USDA Forest Service, Pacific Southwest Region, Forest Pest Management, San Francisco, California.

One of the problems encountered was the relative shortness of the timeframe, or window, suitable for acquiring aerial photographs. Conifers killed in late summer or early fall display visible indications of death over a period of time during the following spring. The probability of capturing fall mortality is increased by photographing early the next summer. In addition, the presence of snow on and under trees adversely affects the quality of photographs and causes excessive eyestrain to photointerpreters. However, the Southwest typically experiences a dry period in the spring during March, April, and May, while relatively heavy, almost daily thunderstorms during the summer monsoons serve to make July and August the wettest months of the year. The photographic window is therefore limited to late May and most of June, the time we scheduled the flights. In fact, this proved to be the best time, in terms of weather, although a series of unseasonable storms caused serious delays and meant that some photoplots were never photographed. The number of alternate plots, comprising about 10 percent of each stratum, which had been selected and drawn on maps and photographs, proved to be too few in some cases. The improvised method of substitution was not altogether successful in reducing the effects of weather, and, as a result, some strata were slightly undersampled. Because some plots which were substituted could not be delineated accurately on the resource photography, it was difficult and time consuming to later locate them on maps and on the ground. The selection of additional alternate plots would alleviate this problem, but is very time consuming.

As mentioned before, plots were selected on the basis of timber type determined from type maps supplied by Forests. The Southwestern Region is currently in the process of updating these maps; as a result, some were of recent origin, but others were based on data acquired almost 30 years ago. In addition, some of the typing, even allowing for the passage of time, appeared to be in error. As a result, several plots were mistyped. This source of error can be reduced by using only up-to-date type maps or by typing photographs after acquisition, but the latter is an expensive process and requires specialized expertise. A related problem, that surfaced in the ground checking phase, is the mosaic nature of stands in the Southwest; stands are typically small and often separated by nonsampled types, consisting of other timber, brush, or meadows. The criterion used to select plots, that each contain at least 50 percent forested land of a single commercial timber type, meant that only a small proportion of the potential plots were chosen, the rest being considered and discarded. It might be argued, given the nature of stands in the Southwest, that the ones we picked are unrepresentative, since they tended to be larger than is normal. In addition, a number of plots which contained only slightly more than the minimum acreage were included in the sample. Yet, when the mortality estimates were expanded, the entire plot was considered to be in the timber type sampled. Possible solutions appear to be (1) to increase the minimum standards, (2) use smaller plots, or (3) type the photographs after acquisition. Increasing the minimum standards would actually increase the bias toward large stands. Decreasing the size of plots would decrease this bias, but would increase the number of primary sample units needed. In

addition, the plot size was originally chosen to fit the effective area of a 9- by 9-inch photograph at a scale of 1:8,000, which was considered the most efficient scale for detection of mortality. Changing the size of the primary sample units would either "waste" part of the effective area or necessitate changing the scale of the photographs. The third solution, to type the photographs after acquisition, would increase the accuracy of the estimates because it allows unforested acres to be deleted and assigns all other acreages to actual type. However, it is expensive and time consuming, and should be done in the very limited time between photographic acquisition and ground checking.

At the time the survey was planned and carried out, an omission survey was not a normal procedure, and there was no means of incorporating the results of such a survey into the statistical analysis. Accordingly, we did not perform this survey; our failure to do so proved to be a serious error. The survey as accomplished seriously underestimates numbers of trees and, to a lesser extent, volumes. The source of this error is twofold; first, normal human error which has been well documented, and, second, the lack of visible signatures typical of some trees. We found, when it was too late to correct, that the symptoms of mortality displayed by trees in the Southwest which are visible on photographs are more ephemeral and less distinctive than those used in California, especially in trees killed by certain pests. For instance, large pines killed by western pine beetle were quite visible on the photographs because death is relatively rapid and the entire crown fades in a short time. However, conifers, especially Douglas-fir and true firs, infected by root rots or dwarf mistletoes, typically display thin crowns for up to several years. When these thin crowns eventually fade to sorrel, the foliage is often too sparse to provide a visible signature, and the tree is considered to be a snag, killed in a previous year. We frequently encountered dwarf mistletoe-infected trees which still retained green foliage in the lower crown, but which appeared as snags on photographs because the leafless portion of the crown obscured the lower, green, or sorrel portion. Dead trees also appear to shed needles more rapidly in the Southwest than in other areas of the West. We commonly observed trees which were green or at most slightly off colored at the time of photography, but, which by the end of the ground check in early December, had not only completely faded, but had lost enough needles that they would then have been considered year-old snags. Since these trees would not have appeared as current mortality on photographs taken the following spring, they constitute a serious source of error which could have been corrected if an omission survey had been done.

It is difficult to envision a survey of this magnitude which does not encounter various problems, small and not so small, which must be solved in order to achieve satisfactory results. Schultz (11) has discussed some of the pitfalls of contracting photographic interpretation and ground checking, including the scarcity of trained personnel. His report should be required reading for anyone who has a

desire to institute a large-scale damage survey. We encountered many of the same problems; in addition, events, such as the discovery of impassable box canyons, early, heavy snowfalls, and an unfriendly rattlesnake (whose aim, fortunately, did not match his aggressiveness), served to relieve the monotony and maintain the alertness of field crews.

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APPENDIX

TABLE 1. Mortality occurring in commercial timber strata in New Mexico and Arizona during the survey year from June 1980 to June 1981

Strata	No. trees	Trees/A	Volume (BF)	Vol./A (BF)	M acres
Northern New Mexico pine	75,508 ± 3,066 (4%)[1]	0.11 ± .004	4,184,102 ± 518,672 (12%)[1]	6.0 ± 0.72	698 (25)[2]
Northern New Mexico mixed conifer	39,332 ± 2,089 (5%)	0.11 ± .01	3,763,048 ± 473,236 (13%)	10.3 ± 1.34	366 (13)
Northern New Mexico spruce-fir	9,799 ± 1,453 (15%)	0.10 ± .02	999,938 ± 417,910 (42%)	10.6 ± 4.45	94 (03)
Arizona pine	88,757 ± 3,524 (4%)	0.06 ± .002	19,874,822 ± 2,260,126 (11%)	12.5 ± 1.38	1,597 (57)
Apache-Sitgreaves NF's	18,224 ± 1,105 (6%)	0.04 ± .002	4,979,136 ± 1,620,830 (33%)	10.7 ± 3.53	465 (17)
Coconino NF	39,228 ± 2,866 (7%)	0.06 ± .004	7,316,391 ± 802,326 (11%)	11.6 ± 1.28	632 (23)
Kaibab NF	31,305 ± 1,728 (6%)	0.06 ± .004	7,579,395 ± 1,355,490 (18%)	15.2 ± 2.74	500 (18)
Apache-Sitgreaves mixed conifer and spruce-fir	19,647 ± 2,520 (13%)	0.15 ± .002	4,738,075 ± 1,159,835 (24%)	36.4 ± 8.74	130 (5)
Total	233,043 ± 5,886 (5%)	0.08 ± .004	33,559,985 ± 2,668,522 (13%)	12.0 ± 1.56	2,791

[1] Percent error.
[2] Percent of total acres.

TABLE 2. Mortality caused by root diseases and other pests

	Tree species[1]	Percent of total trees killed	Percent of total volume lost
Overall			
Root diseases and bark beetles	All	24 ± 2	22 ± 6
Root diseases and dwarf mistletoes	PP, DF, WF	10 ± 2	07 ± 2
All root disease complexes	All	34 ± 3	30 ± 6
Bark beetles alone	All	31 ± 2	30 ± 4
Bark beetles and dwarf mistletoes	PP, DF, WF	21 ± 2	21 ± 3
All injury complexes	All	11 ± 2	18 ± 4
New Mexico pine			
Root diseases and bark beetles	PP, WF	22 ± 4	11 ± 3
Root diseases and dwarf mistletoes	PP, DF, WF	9 ± 2	9 ± 2
All root disease complexes[2]		31 ± 4	20 ± 4
Bark beetles alone	PP	27 ± 3	24 ± 7
Bark beetles and dwarf mistletoes	PP, DF	28 ± 5	32 ± 9
Injury complexes	PP, DF, WF	7 ± 1	15 ± 6
New Mexico mixed conifer			
Root diseases and bark beetles	WF	43 ± 8	34 ± 8
Root diseases and dwarf mistletoes	DF, PP	10 ± 3	8 ± 3
All root disease complexes		53 ± 9	42 ± 9
Bark beetles alone	DF, PP, WF	24 ± 4	21 ± 6
Bark beetles and dwarf mistletoes	DF, PP	17 ± 5	34 ± 15

[1] PP = ponderosa pine; WF = white fir; DF = Douglas-fir; CF = corkbark fir; ES = Engelmann spruce.

[2] Includes minor complexes.

TABLE 2. Mortality caused by root diseases and other pests--Continued

	Tree species	Percent of total trees killed	Percent of total volume lost
New Mexico spruce-fir			
Root diseases and bark beetles	CF, ES	67 ± 21	53 ± 15
Root diseases alone	ES, CF, DF	26 ± 7	46 ± 42
All root disease complexes	ES, CF, DF	93 ± 22	99 ± 45
Apache-Sitgreaves pine			
Root diseases and bark beetles	PP	10 ± 3	30 ± 29
Root diseases and dwarf mistletoes	PP	19 ± 7	9 ± 7
All root disease complexes		30 ± 8	39 ± 30
Bark beetles alone	PP	33 ± 9	15 ± 6
Bark beetles and dwarf mistletoes	PP	19 ± 5	19 ± 9
Injury complexes	PP	14 ± 8	24 ± 17
Apache-Sitgreaves mixed conifer			
Root diseases and bark beetles	PP, DF, WF, ES	34 ± 11	46 ± 24
Root diseases and dwarf mistletoes	DF, PP	17 ± 8	7 ± 3
All root disease complexes		55 ± 14	55 ± 24
Bark beetles and dwarf mistletoes	DF, PP	42 ± 15	45 ± 16
Coconino pine			
Root diseases and bark beetles	PP	16 ± 5	20 ± 9
Root diseases and dwarf mistletoes	PP	10 ± 4	8 ± 4
All root disease complexes		28 ± 6	29 ± 10
Bark beetles alone	PP, DF	37 ± 8	34 ± 10
Bark beetles and dwarf mistletoes	PP, DF	18 ± 5	18 ± 4
Injury complexes	PP, DF	14 ± 4	19 ± 9

TABLE 2. Mortality caused by root diseases and other pests-Continued

	Tree species	Percent of total trees killed	Percent of total volume lost
Kaibab pine			
Root diseases and bark beetles	PP	2 ± 1	4 ± 3
All root disease complexes	PP	4 ± 1	4 ± 3
Bark beetles alone	PP	69 ± 9	64 ± 11
Bark beetles and dwarf mistletoes	PP	4 ± 3	1 ± 1
Injury complexes	PP	21 ± 6	30 ± 10

TABLE 3. Number of trees killed and dead tree volume estimates by important pests

	No. of trees	Percent of total	Vol. (MBF)	Percent of total
Dendroctonus brevicomis LeConte	38,061	17	9,741	35
Armilleriella mellea (Vahl. ex Fr.) Karst	26,759	12	3,956	14
Arceuthobium sp.	27,687	12	2,798	10
Dendroctonus pseudotsugae Hopkins	7,977	4	2,465	9
Lightning injury	5,116	2	2,432	9
Dendroctonus ponderosae Hopkins & *Dendroctonus adjunctus* (Blandford)	16,127	7	1,871	7
Ips sp.	20,234	9	1,546	6
Scolytus ventralis LeConte	22,741	10	1,016	4
Fomes annosus (Fr.) Cke.	8,057	4	878	3
Dendroctonus rufipennis (Kirby)	3,712	2	285	1

TABLE 4. Relative frequencies of shoestring and annosus root rots

Strata	Percent of total dead trees		Percent of total vol.	
	shoestring root rot	annosus root rot	shoestring root rot	annosus root rot
New Mexico pine	8	2	5	<1
New Mexico mixed conifer	15	9	14	7
New Mexico spruce-fir	38	14	44	11
Apache-Sitgreaves pine	7	<1	12	<1
Coconino pine	12	<1	10	6
Kaibab pine	1	<1	1	<1
Apache-Sitgreaves mixed conifer and spruce-fir	24	<1	29	<1

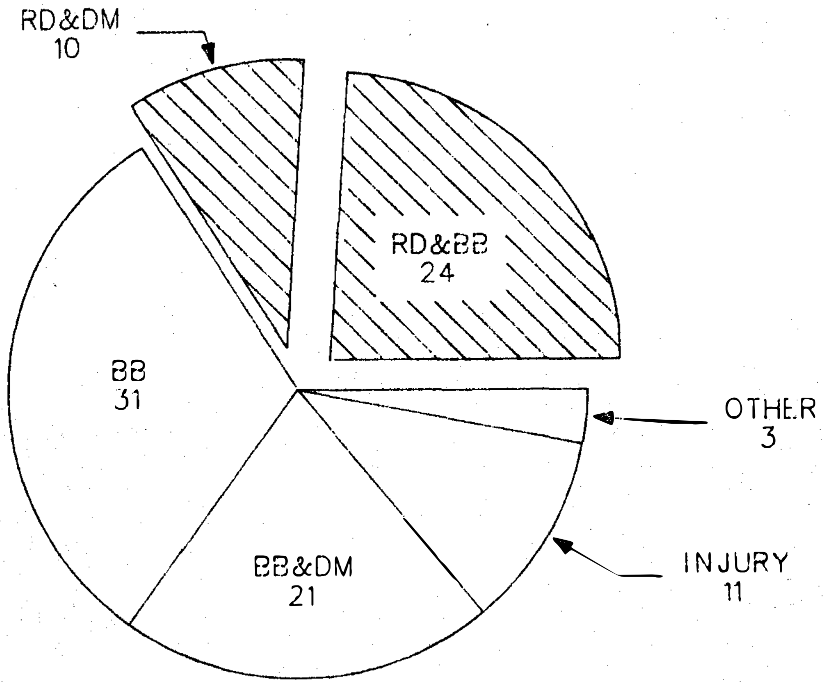
TABLE 5. Mortality and volume loss by site class

Site class	No. dead trees	Percent of total	Vol. (BF)	Percent of total	Average tree size (BF)
≧90	11,824 ± 2,295	6.0	1,813,611 ± 612,690	6.8	153
80-89	16,407 ± 2,984	8.4	1,923,865 ± 572,815	7.2	117
70-79	21,202 ± 2,754	10.8	3,051,106 ± 797,306	11.5	144
60-69	42,393 ± 5,095	21.6	4,849,476 ± 766,187	18.3	114
50-59	49,180 ± 4,425	25.1	4,652,977 ± 570,536	17.5	94
40-49	41,997 ± 4,183	21.4	8,836,341 ± 1,511,276	33.3	210
<40	13,084 ± 3,187	6.7	1,426,933 ± 418,081	5.4	109

TABLE 6. Mortality and volume losses by tree species

Species	No. dead trees	Percent of total	Vol.	Percent of total
Ponderosa pine	148,952 ± 6,994	63.9	25,286,213 ± 2,522,473	75.4
Douglas-fir	30,465 ± 4,133	13.1	4,506,182 ± 1,125,133	13.4
White fir	37,763 ± 4,701	16.2	2,353,176 ± 695,852	7.0
Corkbark fir	9,241 ± 1,604	4.0	765,000 ± 248,074	2.3
Engelmann spruce	5,365 ± 1,815	2.3	548,897 ± 227,379	1.6
Southwestern white pine	1,246 ± 1,246	0.5	100,616 ± 100,616	0.3
Total	233,032	100.0	33,560,084	100.0

FIGURE 1. Mortality caused by root diseases and other pests in six National Forests in northern New Mexico and Arizona, expressed as percent of total trees killed and volume lost. RD = root diseases; BB = bark beetles; DM = dwarf mistletoes



TREES KILLED

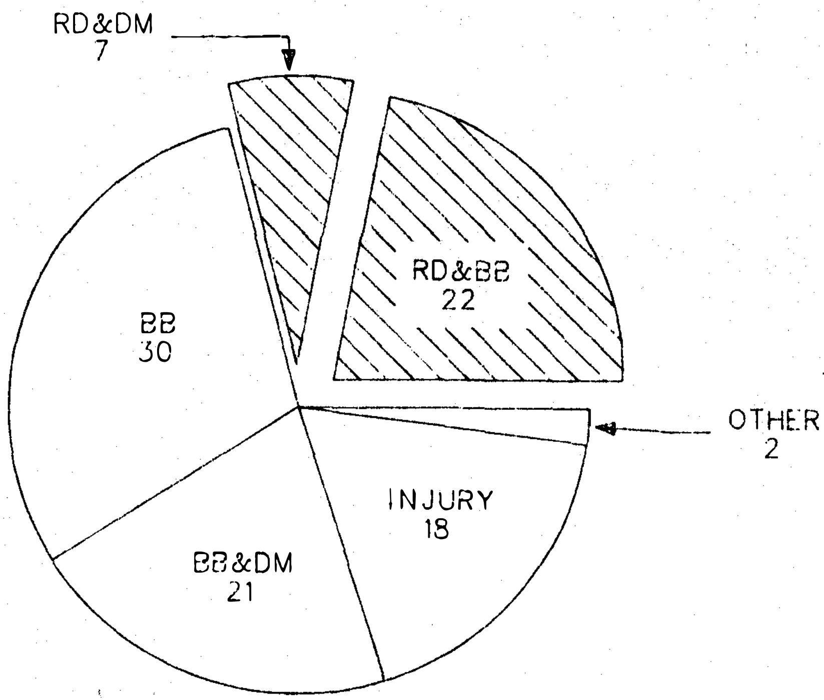


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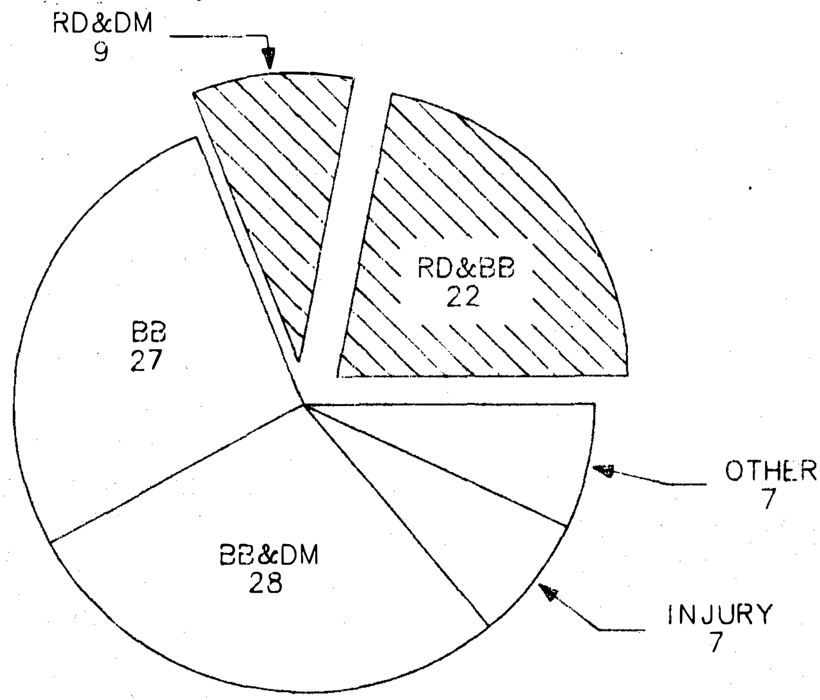
FIGURE 2. Mortality caused by root diseases and other pests in the northern New Mexico pine stratum, expressed as percent of total trees killed and volume lost. RD = root diseases; BB = bark beetles; DM = dwarf mistletoes



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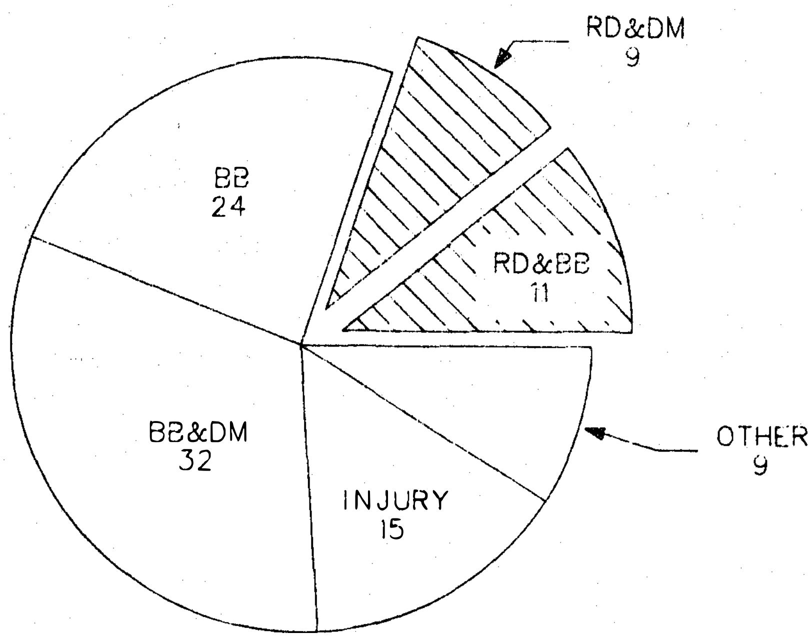

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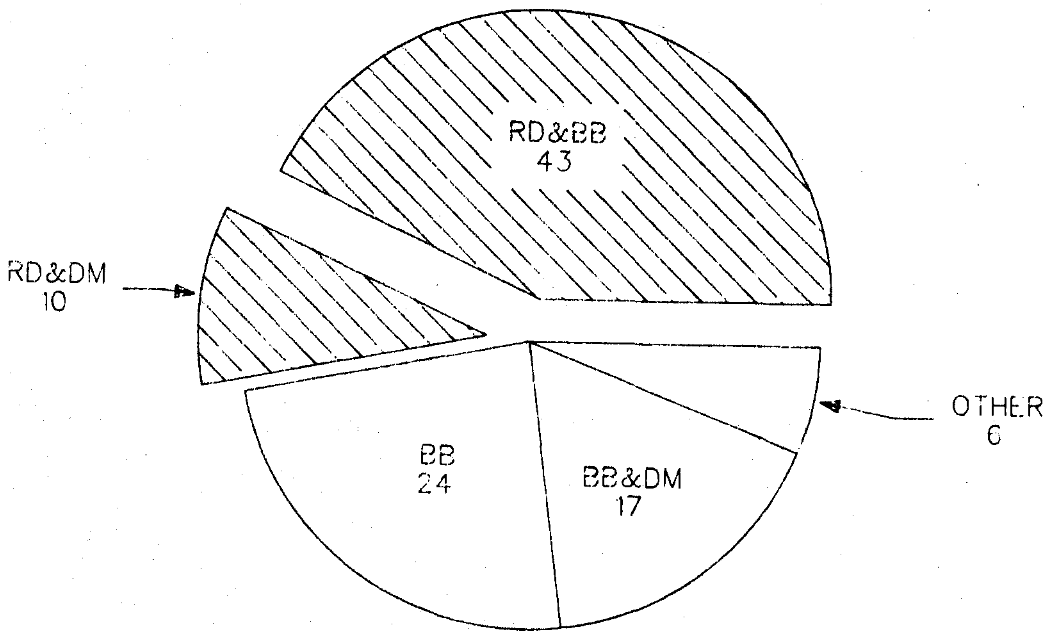
FIGURE 3. Mortality caused by root diseases and other pests in the northern New Mexico mixed conifer stratum, expressed as percent of total trees killed and volume lost. RD = root diseases; BB = bark beetles; DM = dwarf mistletoes



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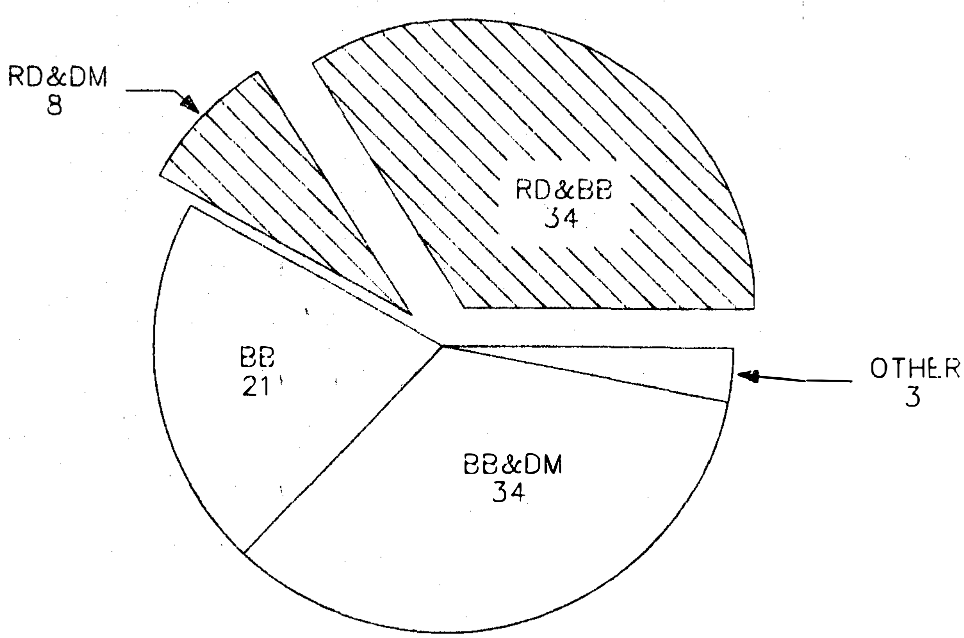

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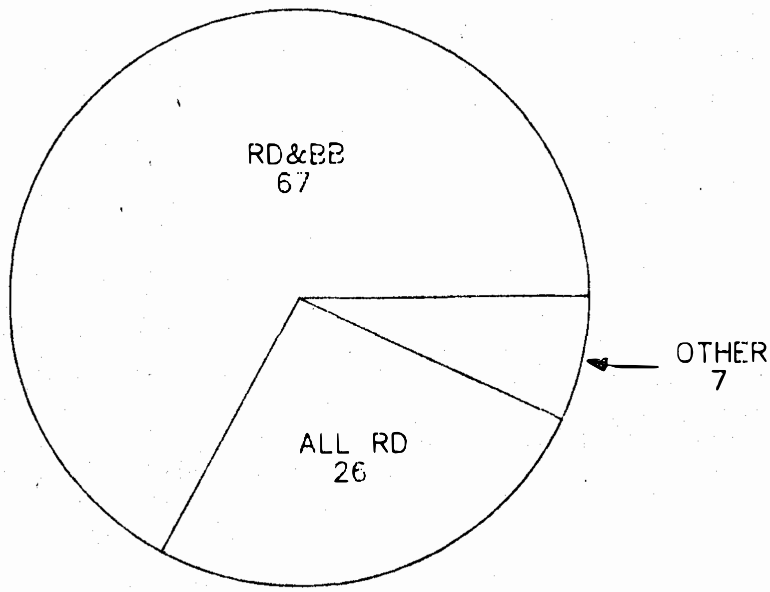
FIGURE 4. Mortality caused by root diseases and other pests in the northern New Mexico spruce-fir stratum, expressed as percent of total trees killed and volume lost. RD = root diseases; BB = bark beetles



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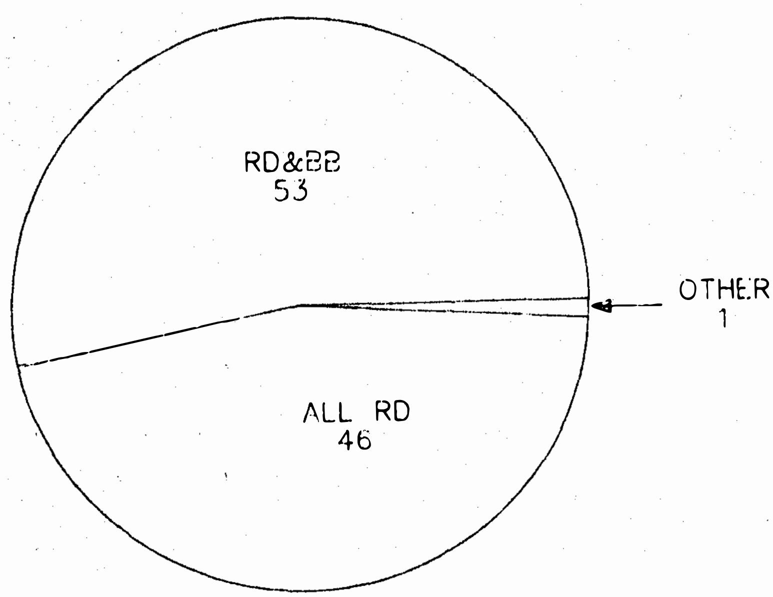

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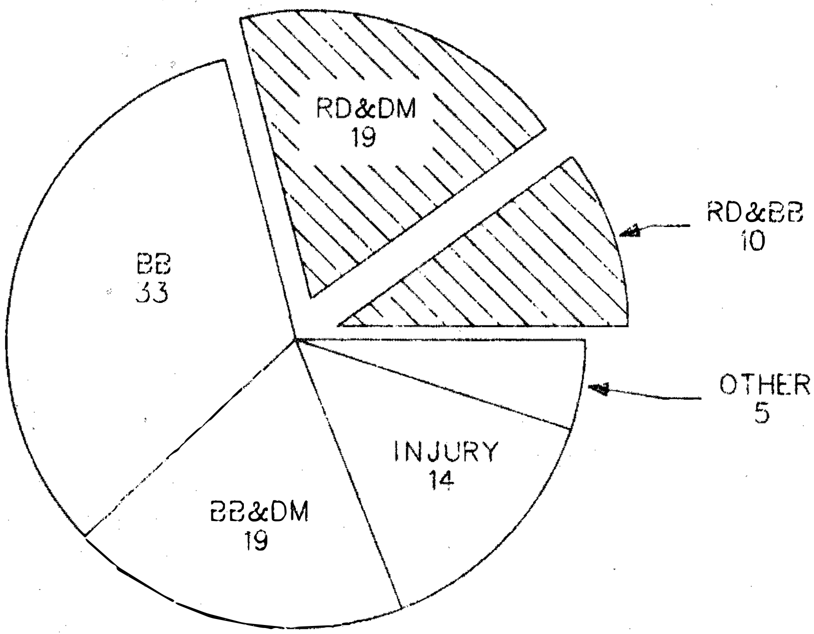
FIGURE 5. Mortality caused by root diseases and other pests in the Apache-Sitgreaves pine stratum, expressed as percent of total trees killed and volume lost. RD = root diseases; BB = bark beetles; DM = dwarf mistletoes



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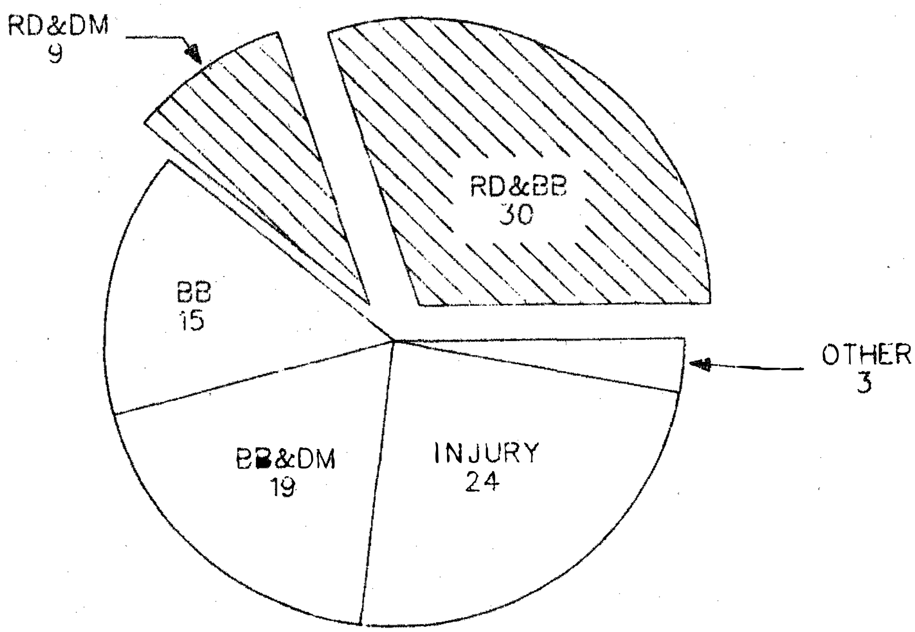

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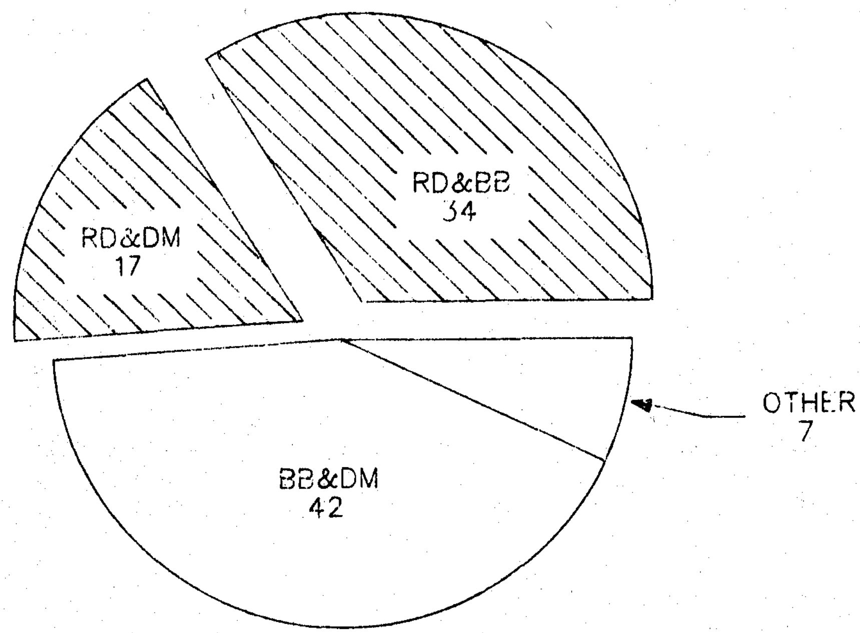
FIGURE 6. Mortality caused by root diseases and other pests in the Apache-Sitgreaves mixed conifer stratum, expressed as percent of total trees killed and volume lost. RD = root diseases; BB = bark beetles; DM = dwarf mistletoes



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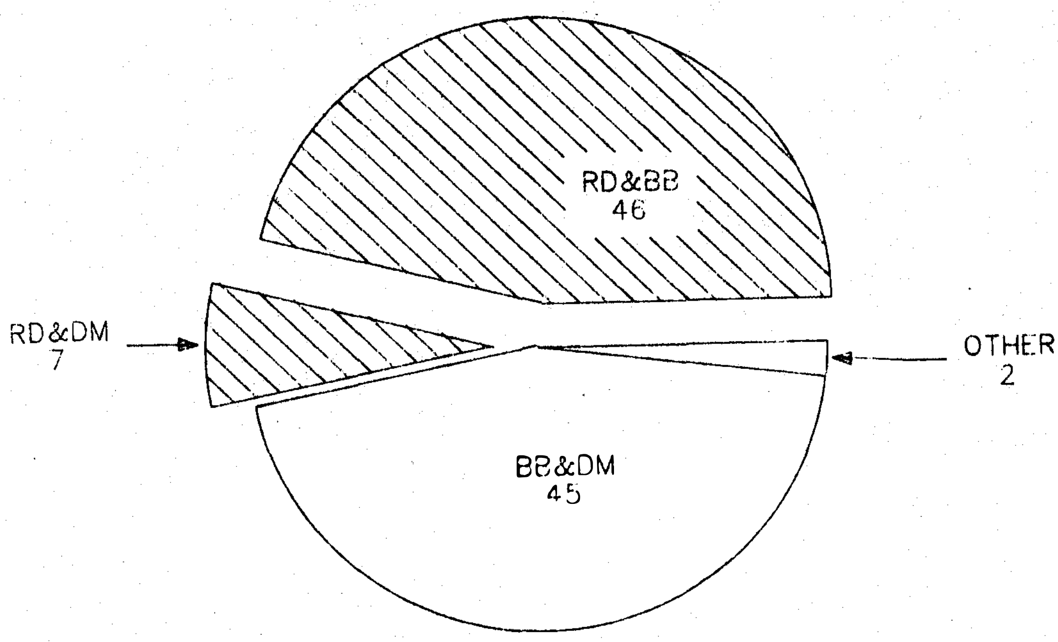

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FIGURE 7. Mortality caused by root diseases and other pests in the Coconino pine stratum, expressed as percent of total trees killed and volume lost. RD = root diseases; BB = bark beetles; DM = dwarf mistletoes

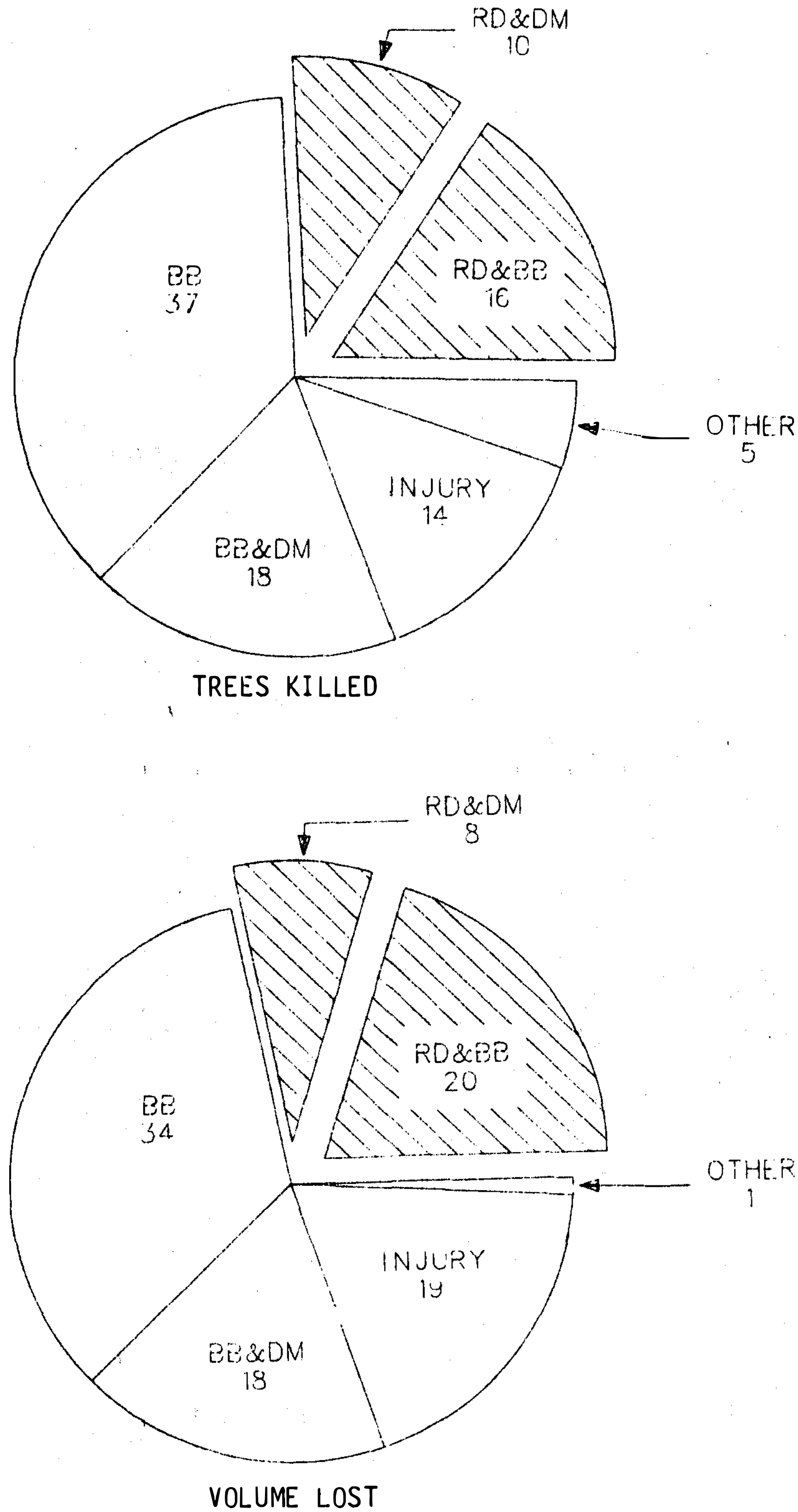
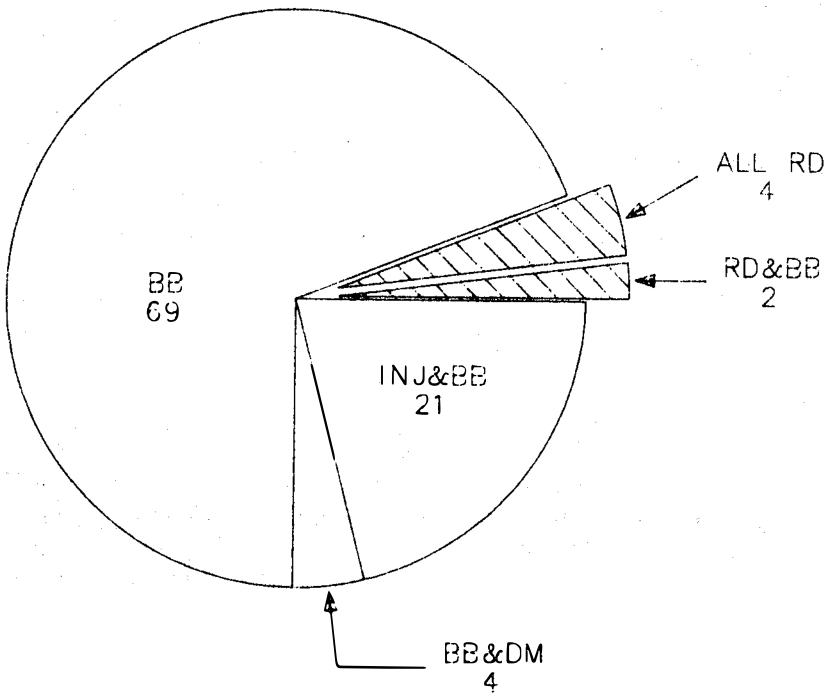
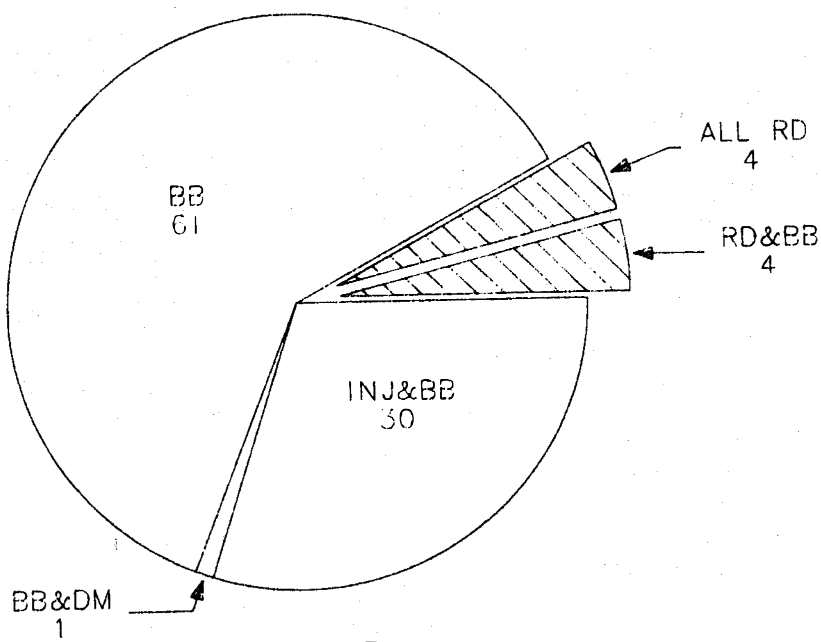


FIGURE 8. Mortality caused by root diseases and other pests in the Kaibab pine stratum, expressed as percent of total trees killed and volume lost. RD = root diseases; BB = bark beetles; DM = dwarf mistletoes



TREES KILLED



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